6.3 Space Control

Control of space will become essential during the next decade. We will depend on satellites to provide Global Awareness and Dynamic Control for our Forces, and *commercial services may be a threat to those Forces.* As commercial involvement of US companies in space increases, *the United States may be called upon to protect nonmilitary space assets from attack by terrorists or a rogue nation.* We should be prepared to execute three missions:[41]

- Protect US military space assets and launch capabilities.
- Deny the use of threat assets.
- Protect allied, non military space assets.

Various antisatellite (ASAT) weapons that direct projectiles or fragments against threat satellites have been developed or proposed. Kinetic energy systems such as these are expensive. The vehicles are complex, and tracking and guidance must be precise. Most of the cost, however, is the result of maintaining readiness to launch within an acceptable time, such as 24-48 hours. There appears to be no way to reduce the cost of readiness in the near future. In the main, space based communication systems are not invulnerable to jamming. The task of directing a laser at a satellite is not an easy one. Laser power of a megawatt or more will be needed, and precision tracking and pointing systems must be developed. We believe, however, that it is possible to develop such a system in less than a decade. *Therefore, we recommend ground-based Directed Energy weapons to attack threats in space.*

It is less obvious that high power microwave (HPM) systems may have a role in space control, such microwave systems could be attractive because they have the potential to produce electronic upset without damaging the structure of a threat satellite. Thus, HPM systems may be more effective at producing temporary denial of capability than a laser. Phasing technology used in radio astronomy could be applicable to the problem. *We should consider the possibility of a very large array of independently phased dipoles spread over a kilometer diameter.* The diodes could be phased to form a sparse synthetic aperture for projecting microwave power into space.

Protection of military satellites might be enhanced to some extent should the application of stealth techniques be possible, but if distributed systems become the norm, the redundancy of systems will provide protection. Solar panel area is large, and panel position cannot always be set to minimize observability. *Even if possible, we do not believe that the increased cost of low observable satellites will be justifiable.*

Because of cost, it is unlikely that many countries will develop ASAT weapons. It is well known that GPS is vulnerable to jamming because of the low power in the navigation message.[42] Power of a few watts can jam the Clear Access (C/A) code at a distance of 10-20 km. Nulling antennas can provide increased jam resistance, but the only long term solution is to increase the signal-to-noise ratio as described above.[43] Protection of other systems can be

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41. Space Applications Volume
42. *Journal of Navigation*; Spring 1993, and SAB Report - *GPS Survivability and Denial*, November 1993
43. Sec. 2.6 of this chapter

enabled by munitions directed by coordinates to the jammer. Current practice is to launch missiles which home on the signal whether it be a jammer or a communication or radar source. Accuracy and kill probability could be improved dramatically by the distributed satellite signal detectors described in Sec. 2.1 coupled to GPS munition guidance. It is possible to field a system whereby cooperative satellites could provide signal coordinates quickly to an accuracy of a few meters, and GPS guided munitions can strike to a comparable accuracy even if the source emits only for seconds, or less. Overall accuracy should be 5-10 meters. It should be possible to build coordinate-targeted missiles having range of 100 km at a cost of $100-150K. This system will provide robust protection against the most common threat to US and allied space assets.

6.4 Force Projection from Space

There are political issues related to the projection of power from space, but we treat only the technological ones. Two classes of weapon have applications from space—directed energy and kinetic energy. Of the two, only the directed energy weapon offers attractive features such as reusability, speed-of-light response, and training and testing features. Kinetic energy weapons having the same energy as orbital weapons can be delivered by ICBM from the CONUS. Response time can be nearly that of an orbiting weapon, and the cost of readiness is lower. *We recommend that the ICBM option with terminal, coordinate guidance be used if delivery of kinetic energy weapons from space becomes an operational requirement.* Of course, the issue of distinguishing nuclear weapons from conventional weapons must be addressed. Therefore, we will discuss space deployment of directed energy weapons.

Because of the large distances from space to target high power radio frequency (HPRF) weapons will require antennas having diameters of 5-10 km and powers of at least kilowatts. If development of extremely lightweight structures and wavefront compensation methods in the microwave frequency range succeed, such weapons will be possible. We believe, though, that the short wavelength and high power of lasers will favor the space deployment of high power lasers rather than HPRF.

Two deployment options are available. First, a laser device can be deployed in space along with beam directing optics and control systems. Space deployment of lasers will involve significant problems in logistics, resupply, and training in addition to those of targeting and control. Consumables in the laser system will result in very high system costs. The minimization of these costs will demand electrical lasers and compact energy storage systems. Phase locked solid state diode lasers are the preferable device because they achieve electrical efficiency of 50 percent and they have excellent beam quality. Large optical elements with wavefront compensation will be essential for long-range capability.

The second option is to construct the laser system on the ground and to deploy targeting mirrors in space. Again, large structures and wavefront compensation to compensate for optical imperfections will be necessary. But, many logistics problems associated with space basing will be eliminated, and more choices of laser will be available. Laser power will not be limited by satellite power or by available fuel. The system satisfies that most basic of principles that one should always minimize the complexity of the space component. The idea of directing ground based lasers with space based mirrors is not new. The new technologies which can be applied to the problem, though, are those of lightweight structures[44] and nonlinear optics.[45] Control technologies will also improve during the next decade. We believe that if projection of directed energy from space becomes a reality it will be in the form of ground based lasers and space based relay mirrors.

7.0 People

New World Vistas looks decades into the future. We predict increasing dependence on autonomous weapons and information systems. During the entire period, we see people as central to Air Force operations. *Therefore, the design of systems must include the "human system" as an integral part.* Increased tempo of operations and reduced Force size will demand that people interact with weapons systems more efficiently than ever before. Science and technology can assist the process of human interaction with the machine of the future. Improved and specialized training can assist the process of interacting with the machine of the present.

7.1 Modeling the Human

We are accustomed to modeling the performance of weapon systems and interactions among systems. We model groups of humans such as Army units in engagement and maneuver models. We do not, however, model the individual behavioral characteristics of humans. Significant improvements in simulations of engagements could be made by including human qualities such as leadership, cohesion, experience, intelligence, and level of training. It has been noted by General Fogleman that simulations have been unable to explain what modelers assessed to be the apparently irrational behavior of the Iraqi Republican Guard during Desert Storm.[46] He correctly notes that continuous bombing by B-52's is likely to provoke strange behavior in anyone. The goal of human psychological modeling should be to include individual behavior in the design of systems and in engagement models.

Detailed physical models of humans will be valuable in the design of weapon systems. Improved modeling of human structure, motion, and performance will provide valuable input to the design of new weapons. These models should describe the response of humans to weapons as well as the interaction of the human with the system.

7.2 Training

Training is one of the largest consumers of Air Force funds. Training efficiency can be greatly improved by making it more individual.[47] The tailoring of training to the individual had its embryonic beginnings in the computer and video training systems which are now common. We believe that it is necessary to further develop technologies related to:

- Personnel selection and classification systems

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44. Space Technology Volume and Materials Volume
45. Directed Energy Volume
46. General Ronald R. Fogleman; Speech - NATO Brunson, Belgium, NATO Air & Ground Component Commander Conference, September 95
47. Human Systems/Biotechnology Volume

- Cognitive and non-cognitive models of the learner and the instructional process
- Computer technology to support training simulations, training equipment, and training management systems

Improved training can be affected through distributed interactive simulations. Simulations which use humans as foils in training will be more realistic than those which use scripted or probabilistic computer responses. Commercial organizations have begun to use interactive simulations in futuristic video games.[48] Participants note realism far superior to that of other video games. It is possible that displays and methods developed by the entertainment industry can be applied to Air Force training problems.

7.2.1 Flight Simulation

Flight simulation is a special case of training which is of special interest to the Air Force. The utility of simulators in commercial airline operations has been demonstrated to be profoundly effective in increasing pilot performance while reducing aircraft training hours. The Air Force must acknowledge that the aircraft it now owns will be the largest part of the fleet in the early years of the 21st century. It is essential that those aircraft be capable until they are replaced by newer ones.

Simulators for transport aircraft use well known technology and training procedures, and equipping the Air Force with simulators which could eliminate almost all training in aircraft is a straightforward process. The initial capital cost will be high, but the life cycle cost of transports will be far less than if aircraft are used for training. There should, however, be continued research into the minimum requirements for meaningful simulation of Air Force flight conditions. For example, can a substantial fraction of flight training be done in simulators without motion? A considerable body of work exists in this area, and the Air Force should integrate it into planning of the simulator "fleet."

Simulators for high performance aircraft are another matter. Only the Air Force, Navy, and Marine Corps can develop the necessary technology and the necessary training and testing programs. It may be that the sense of "being there"[49] requires the simulation of sensations which are not required for a transport aircraft. However, total fidelity of "being there" in simulation is very expensive and may not be necessary. *The relationship of artificial sensation* [50] *to training effectiveness should be investigated carefully.* For example, it is possible to build a simulator which will produce appropriate g-forces on the pilot. The forces would be produced by a rotating device with smaller radii of curvature than experienced in a fighter aircraft, but the sensation could be made quite accurate. It is likely that joint programs in this area could be very productive.

7.3 Education

Training and education differ in that education is less specific and more encompassing than training. Training produces the capability to perform a limited number of specified jobs

48. Sec. 7.4.1 of this chapter
49. Sec 7.4 of this chapter
50. Information Technology Volume

with high efficiency while education prepares a person to respond effectively to unanticipated situations. The Air Force of the 21st century will be far more complex and technical than the current Force. That situation will be partly the result of the use of higher technology in weapon systems, but it will result mostly from the integration of systems as we have described. Air Force people of the next century must be problem solvers in a milieu which is constantly changing. The only known approach to such issues is through education.

Internal technical capabilities in the Air Force Laboratories will decline as the result of political and budget forces. The people who purchase weapon systems must be “smart buyers,” but it is unlikely that they can achieve “smart buyer” capability unless they are educated in a technical field and have some experience working in that field.

We suggest that the Air Force increase the number of technical degrees at the Masters level substantially through funding of degrees at both AFIT and at Universities. PhD. degrees should be increased as well, but a careful study should be done to determine appropriate staffing levels. Quality of a degree should be a factor rather than simply its existence. Rating system for Universities and Colleges exist. AFIT should participate to the extent that its curriculum overlaps that of civilian schools. *Degree quality should be a factor in civilian and military promotion.*

Practical experience beyond degree should be a part of technical education. As Defense Laboratories accommodate fewer people, experience can be gained by assignments to industry and National Laboratories. Buyers with lab or industry experience will be far “smarter” than those without.

7.4 Human-Machine Interaction

The Air Force will depend increasingly on computer-driven operations at high tempo. Errors and delays associated with the interaction of human and machine can cost lives. The human is fundamentally an analog device, and the computer is a digital device. We communicate with computers through the keyboard and the mouse or through modifications of those devices. Neither permits much creativity. Both operate at bandwidths below that of the brain-eye-hand combination. Rapid unanticipated trained response such as that of a fighter pilot in combat is not possible, in general, with current computer input systems. Flight simulators are, of course, exceptions.

Technology can increase the speed of interaction by reducing the inertia of mouse and keyboard. For example, one can use eye motion to direct a computer cursor rather than a mouse or roller ball. Marginal speed increases can result, but the fundamental nature of the interaction does not change. Speech interpretation technology is developing, but it, too, will not lead to a substantial increase in the speed of interaction. Speech, after all, is highly redundant. The rate of information flow in speech is much slower than the rate of human motor response, such as, pushing a control button.

We admit to having no specific suggestions for increasing the bandwidth of human-machine interactions. *We do, however, recommend that research in methods which have the potential for changing the inherent qualities of that interaction while increasing the speed of interaction* *be aggressively pursued.* The ultimate interaction is thought control.[51] The direct coupling of brain and machine is beginning now with applications in injured and diseased victims. The Air Force should aggressively encourage and exploit this emerging technology.[52]

7.4.1 Commercial Technology

Entertainment companies are developing at breakneck speeds new ways for humans to interact with machines . The intensity of the battle among companies is indicated by their being among the most profitable corporations in the world. While companies do not publish their investments in technology development, it is probable that these investments dwarf that of the Department of Defense (DoD). It is certainly true that the best students in computer and information science are vying for positions in entertainment companies.

It may be that no specific products of the entertainment industry will be of use to the Air Force. However, the thrust of entertainment technology is to convey a sense of “being there” to an audience or to a group of participants. Successful development of such a technology would qualify it as revolutionary. The impact on teleconferencing, collaboration at a distance, flight simulation, UCAV operation, and many other applications would be enormous. *We urge the Air Force to establish continuing contact as closely as possible with entertainment organizations.*

7.5 Chemical Intervention

It is a fact that human operational performance can be enhanced or extended in time by chemical means. The issue is to what extent enhancements can be achieved without side effects. Air Force people will be called upon to travel large distances and to operate at peak performance immediately for extended periods. *Research on means, chemical and other, to reduce the physical and psychological effects of large changes in longitude (“jet lag”) should be continued*. In life-threatening situations it will sometimes be necessary to extend the time over which a person can function at an acceptable level without rest. *Although we believe that such extension of performance can never be completely free of side effects, the search for effective drugs which minimize these effects should be continued.*[53]

8.0 Primary Technologies

At this point the reader has probably concluded that the technological Air Force of the 21st century may be effective, but that it will certainly be incredibly complicated and unaffordable. If the capabilities described earlier were developed as the sum of many systems, both statements would be true. In fact, if the overall capability of the Force were merely the sum of capabilities of individual systems, a modern Air Force would be unaffordable. We have emphasized that the strength of *New World Vistas* technologies lies in their integration. To demonstrate this assertion we will identify the individual technologies necessary for achieving the result we propose. A detailed list and recommended actions will be given in Chapter III. Technologies marked with a (R) will generate revolutionary capabilities. Technologies marked with an asterisk (*) will be pursued in both commercial and military forms. It is currently not clear whether the Air Force decision should be to develop or to buy. They are duplicated on the list.

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51. Information Technology Volume
52. & 53. Human Systems/Biotechnology Volume

Technologies to be developed:

- (R)UCAV structures and engines - including hypersonic operation
- Remote control technologies
- Composite, tailored materials for air and space
- (R)Large lightweight structures for optics and antennas
- Nonlinear optic compensation
- (R)High power, short wavelength lasers with emphasis on phased arrays
- (R)High power radio frequency sources
- (R)Active and IR stealth
- (R)Point of use delivery starting with low cost precision airdrop
- Next generation airlifter - higher wing and engine efficiencies
- (R)Automated, reusable space launch vehicles with “airplane-like” operations
- High Isp engines for low earth orbit flight
- High bandwidth laser communication for satellite and aircraft cross- and down-link*
- (R)Distributed satellite vehicles and sensors
- Precision station keeping and signal processing for distributed satellite constellations
- Radiation resistant satellites
- Precise positioning overlaid on military and commercial information
- (R)High precision, jam resistant GPS
- Hyperspectral sensing and target identification at low spatial resolution
- (R)Human-Machine interactions*
- (R)Information munitions
- Information protection
- Chemical enhancement of biological functions
- Continuous simulation
- Secure operations across large networks having secure RF components*
- Language translation of stylized language
- Micro-electro-mechanical systems for sensing and manipulating*
- Nuclear hardened electronics

Technologies to buy:

- Software tools and languages
- High bandwidth laser communication for satellite and aircraft cross- and down-link*
- (R)Human-Machine interactions*
- Information protection*
- Operations with large databases*
- Secure operations across large networks having secure RF components*
- Micro-electro-mechanical systems for sensing and manipulating*

Services and equipment to buy without development:

- Mapping of the world to 1 m[53]
- High speed processors
- Space launch
- Satellites
- Focal Plane Arrays
- Database software
- Data compression systems
- Computer displays
- Networking technologies
- Direct downlink broadcast equipment
- Satellite to aircraft communication equipment
- Fiber and satellite communication services
- Training systems

There are, of course, support technologies which accompany the major ones. We believe that the reader will agree that the list is manageable if not short. Much of the work listed is in progress today either in DoD or commercial laboratories. Most of the components of information systems can be purchased today.

9.0 Conclusion

We have described the technologies which will make the United States Air Force the most capable and respected Air and Space Force in the world of the 21st century. All of the capabilities enabled have connections to the other Services, and provisions are made for allied

53. Wall Street Journal, November 30, 1995, pp1

operations across networks, databases, and languages. Response times enabled by these technologies and concepts will be measured in seconds for mission generation or, even in microseconds for information responses. The technologies described are at the edge of the currently possible, or, even beyond the edge for a few years. Some of them may not materialize as warfighting capabilities. Forecasting is not an exact science, and the path will wind as it disappears into the shadow of the future. We guarantee the journey to be productive even if the road ends at an unexpected place.

It is incumbent upon the members of the SAB, Air Force technologists, and warfighters to discuss and refine the concepts presented here. The capabilities described are natural ones for scientists and technologists, but we must transform the technical-operational concepts into forms more useful to the operational Air Force. Then, we must transform the concepts into technology programs. Finally, we must transform the programs back into capabilities. When the product of the three transformations is unitary, that is, the result is the same as the starting point, we will have reached a true understanding among all participants.